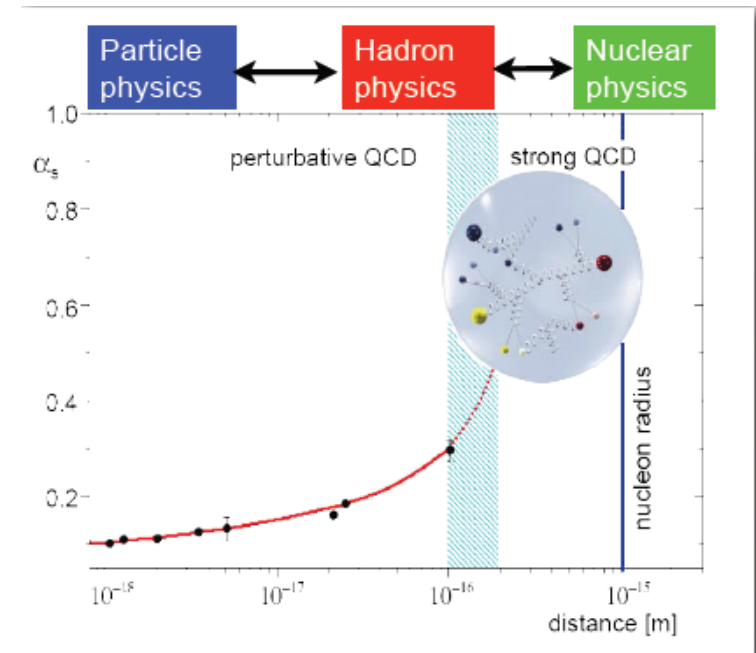
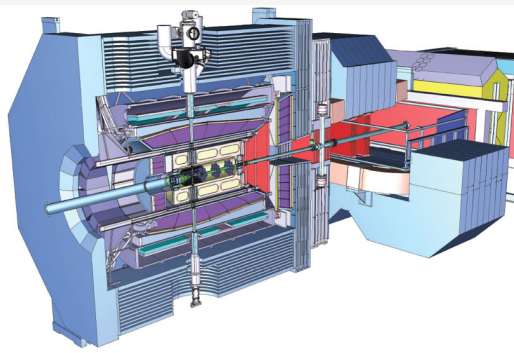


Open questions in QCD (some..)

- **Confinement:** *why free quarks are not observed?*
- **Origin of the hadron mass:** the Higgs mechanism accounts for some percent of the hadron mass
- **How are color neutral objects formed?**
- Establish existence and properties of **exotics, hybrids, glueballs**
- **Structure of the nucleon** (charge, magnetic, spin distributions)

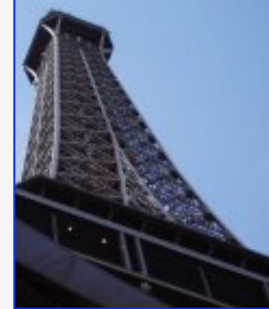


The PANDA experiment at FAIR



Egle Tomasi-Gustafsson

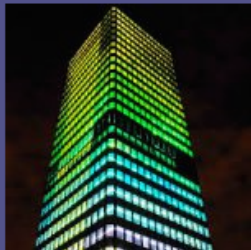
*CEA, IRFU, DPhN and
Université Paris-Saclay, France*



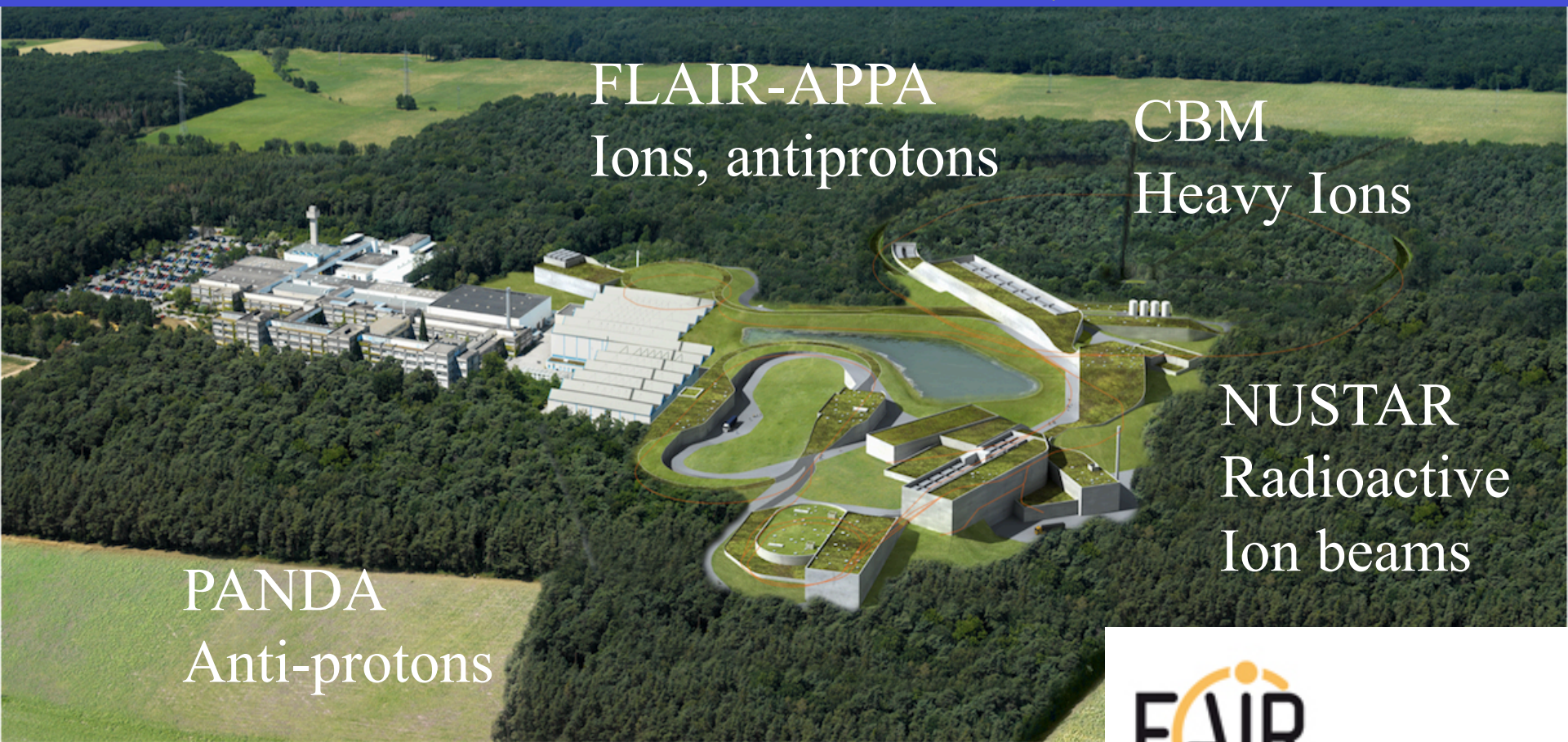
On behalf of the  **PANDA** Collaboration

Low Energy Antiproton Physics Conference 2018

UPMC, Paris, March 12th to 16th, 2018



Facility for Antiproton and Ion Research (Darmstadt/Germany)



FLAIR-APPA
Ions, antiprotons

CBM
Heavy Ions

NUSTAR
Radioactive
Ion beams

PANDA
Anti-protons

All physics communities
are represented



Facility for Antiproton
and Ion Research
in Europe GmbH



Antiprotons at FAIR

<http://www.fair-center.eu/>

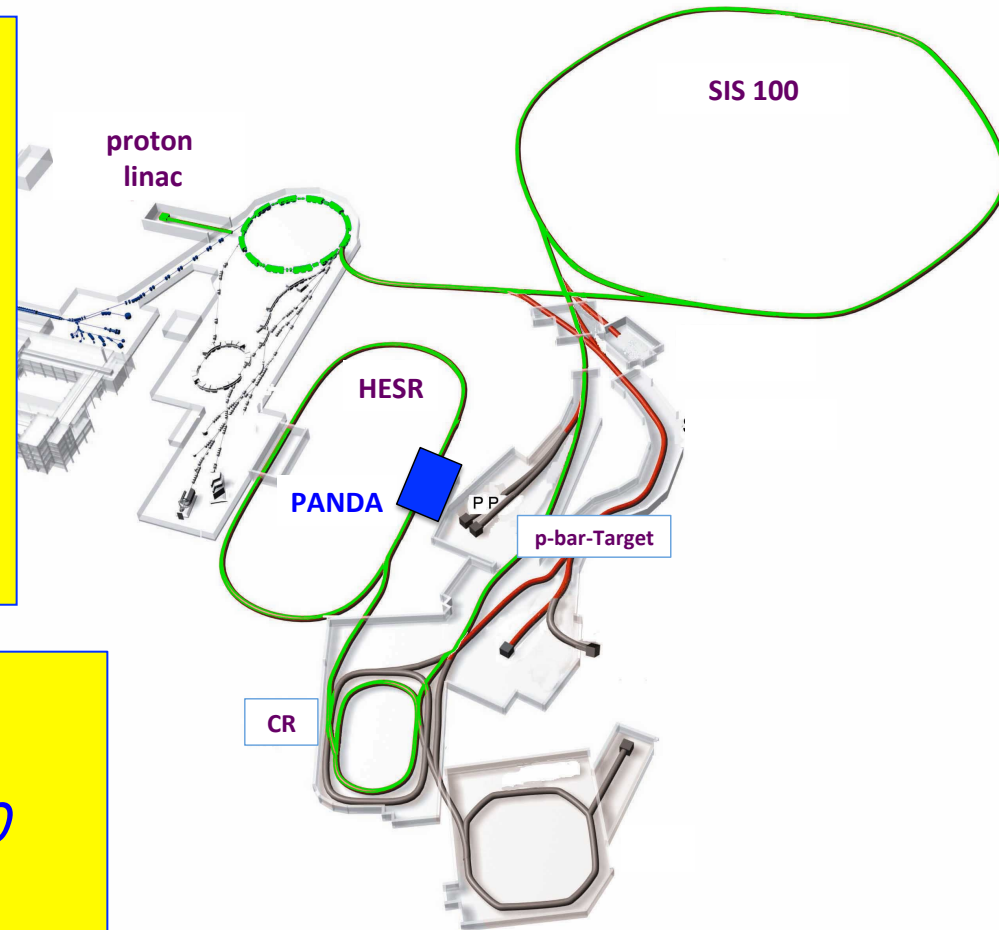
<http://www-panda.gsi.de/>

Parameters of HESR

- Injection of $p\bar{p}$ at 3.7 GeV
- Slow synchrotron
- Momentum 1.5-15 GeV/c
- Luminosity $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
(up to $L_{\text{peak}} \sim 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$)
- Beam cooling

$p\bar{p}$ production

- Proton Linac 70 MeV
- Accelerate p in SIS18/SIS100
- Produce $p\bar{p}$ on NI/Cu target
- Collect $p\bar{p}$ in CR
- Storage in HESR



Antiproton facilities

Experiment	Years	Intensity \bar{p}/s	Momentum range [GeV/c]	$\Delta p/p$
CERN -LEAR	1983-1996	$2 \cdot 10^6$	0.06-1.94	10^{-3}
FermiLab 45% polarized \bar{p}	1985-2011	$2 \cdot 10^6$ 10^4	<8.9 (Low energy beams)	10^{-4}
PANDA		$2 \cdot 10^7$	1.5-15	10^{-5}

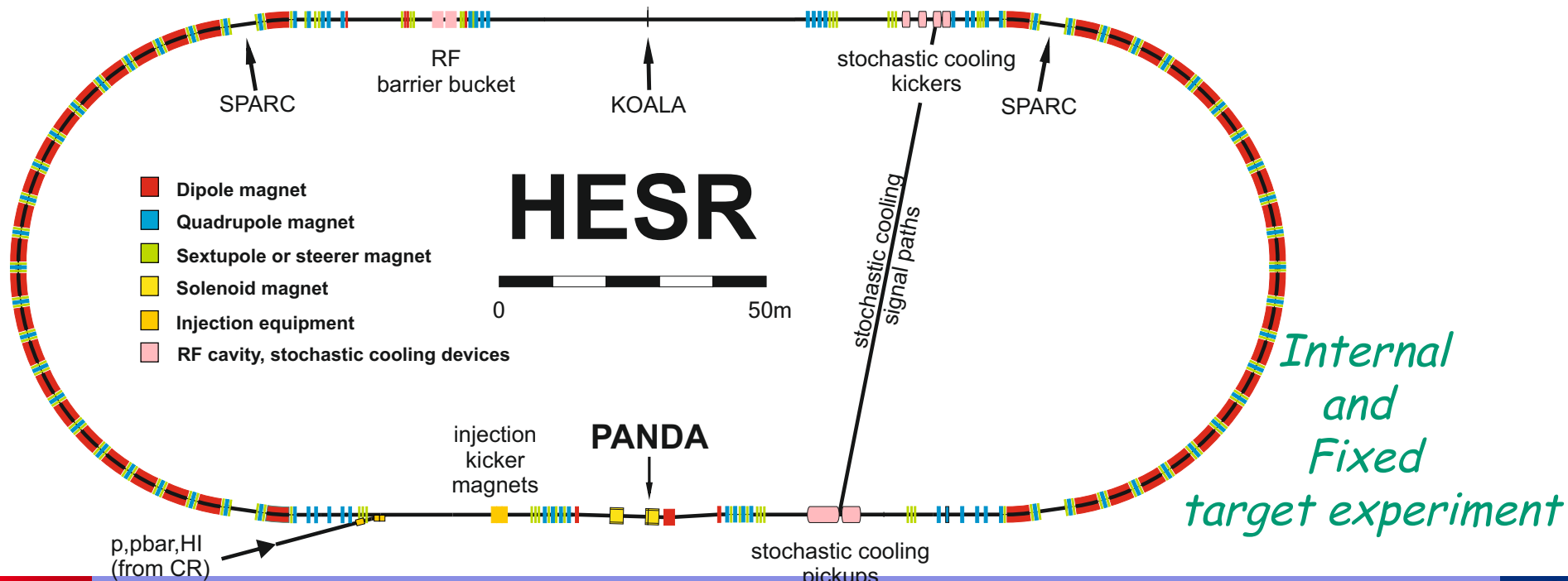
Panda will have:

- Better luminosity*
- Better beam momentum resolution*
- Better detector (coverage, PID, magnetic field..)*

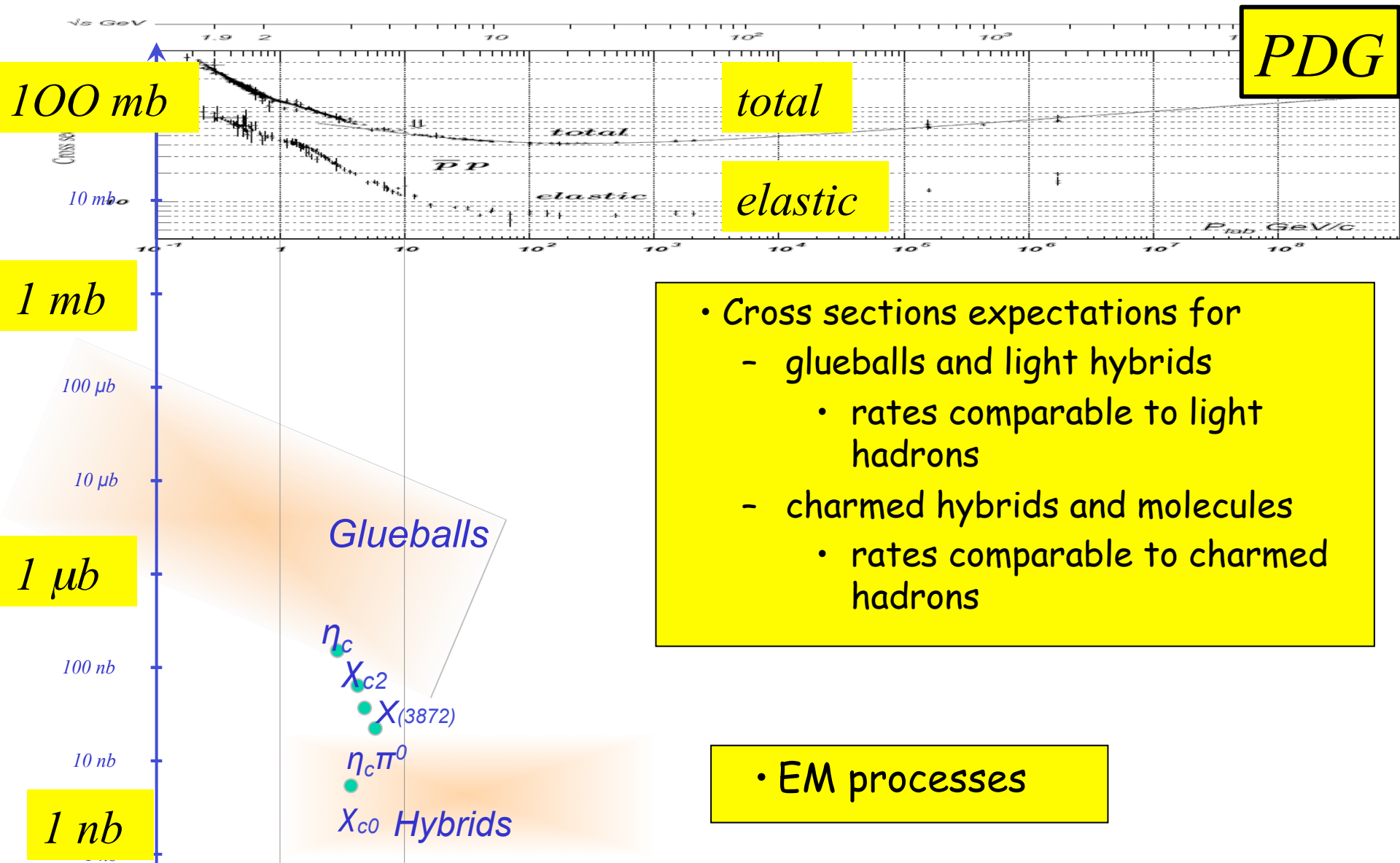


High Energy Storage Ring

Mode	High Resolution	High Luminosity
Momentum range	1.5 – 15 GeV/c	1.5 – 15 GeV/c
Energy range	2.3 – 5.5 GeV	2.3 – 5.5 GeV
Stored antiprotons	10^{10}	10^{11}
Peak luminosity	$2 \cdot 10^{31} \text{ cm}^{-2}\text{s}^{-1}$	$2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
$\Delta p/p$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$



Exclusive Final States

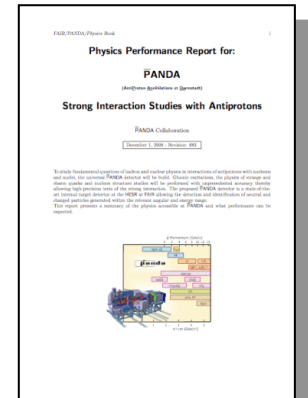
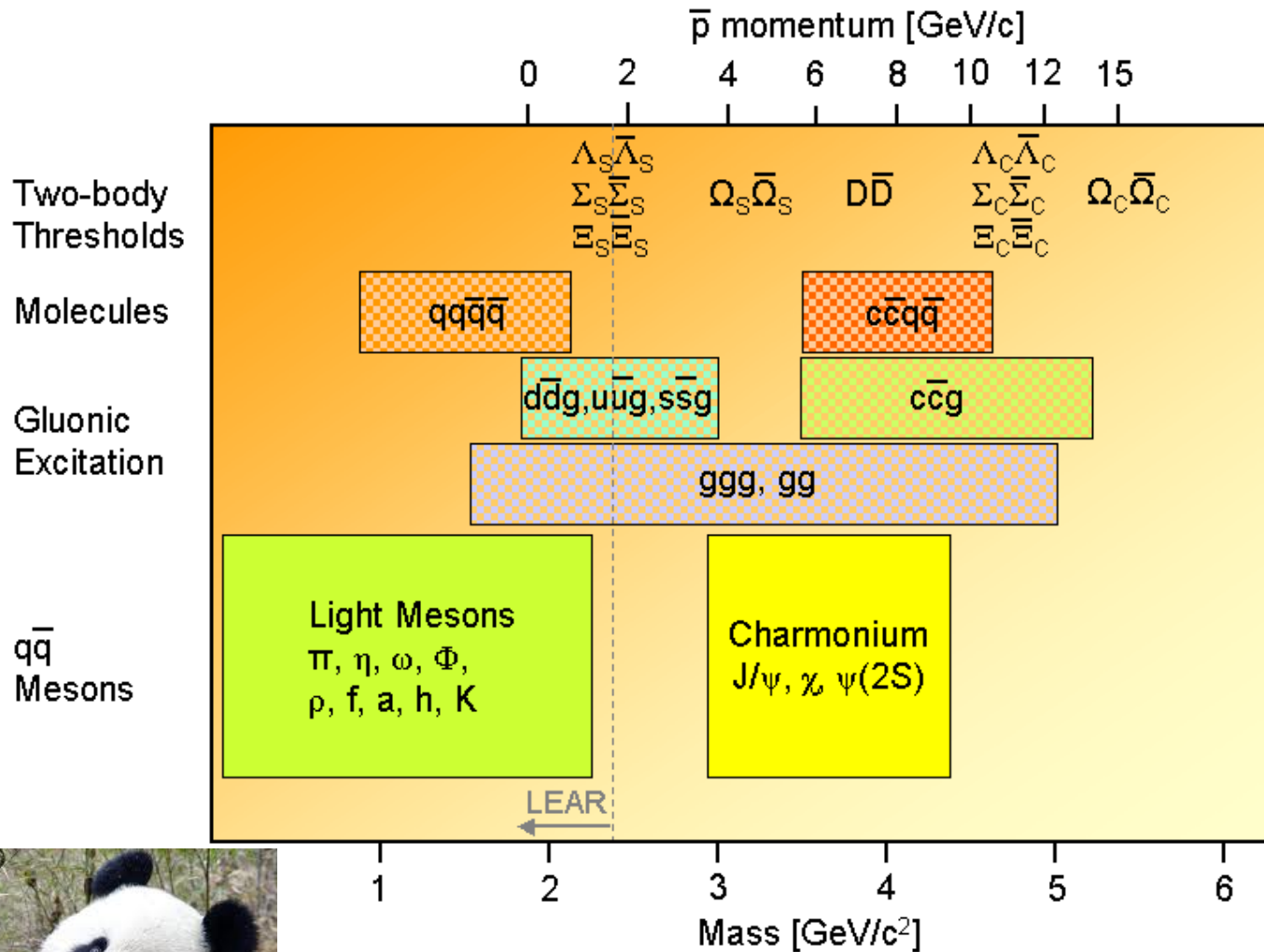


- Cross sections expectations for
 - glueballs and light hybrids
 - rates comparable to light hadrons
 - charmed hybrids and molecules
 - rates comparable to charmed hadrons

• EM processes



Hadron Physics



arXiv:0903.3905v1



QCD bound states

Hadrons in nuclear matter

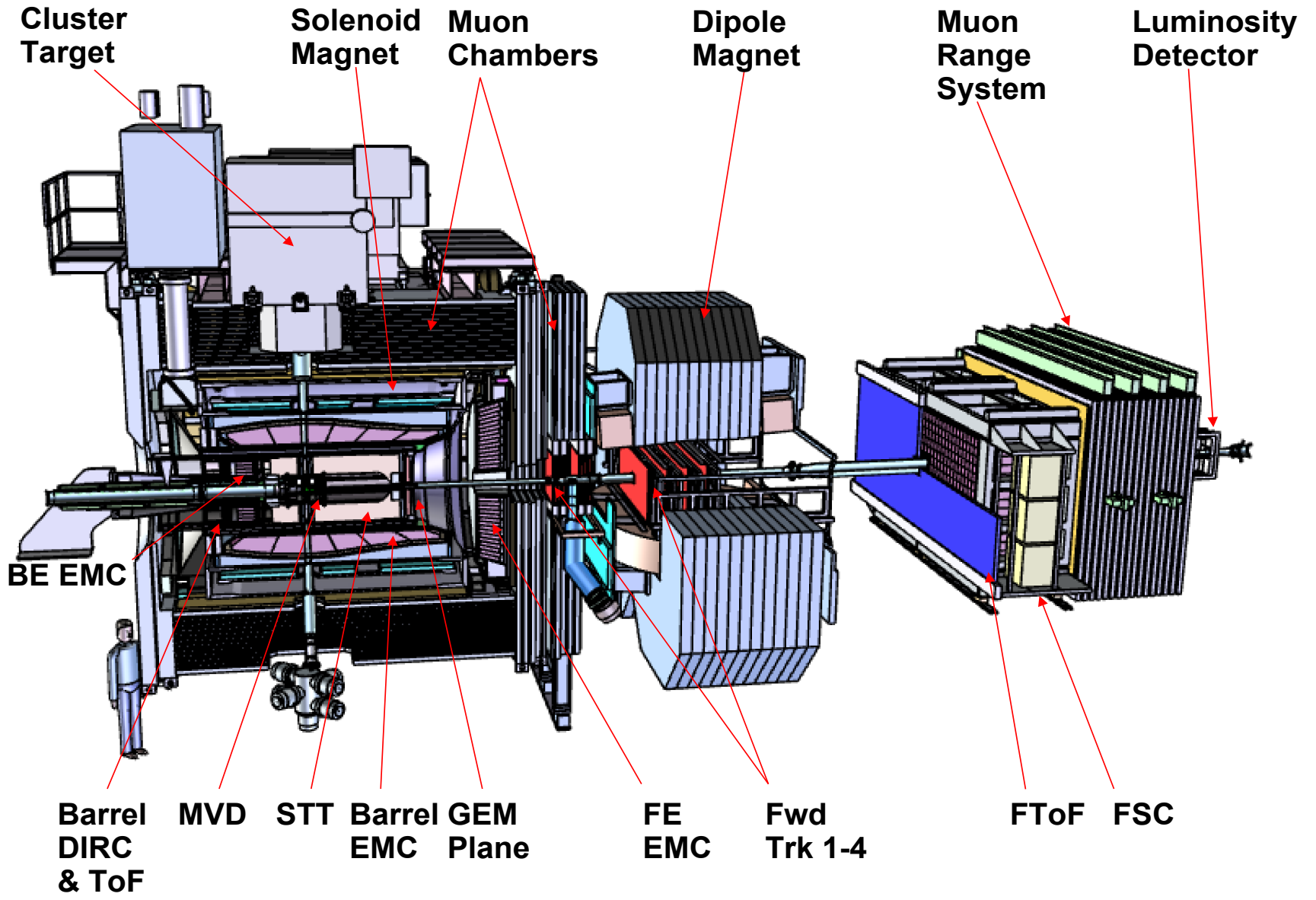
Electroweak physics

Electromagnetic processes

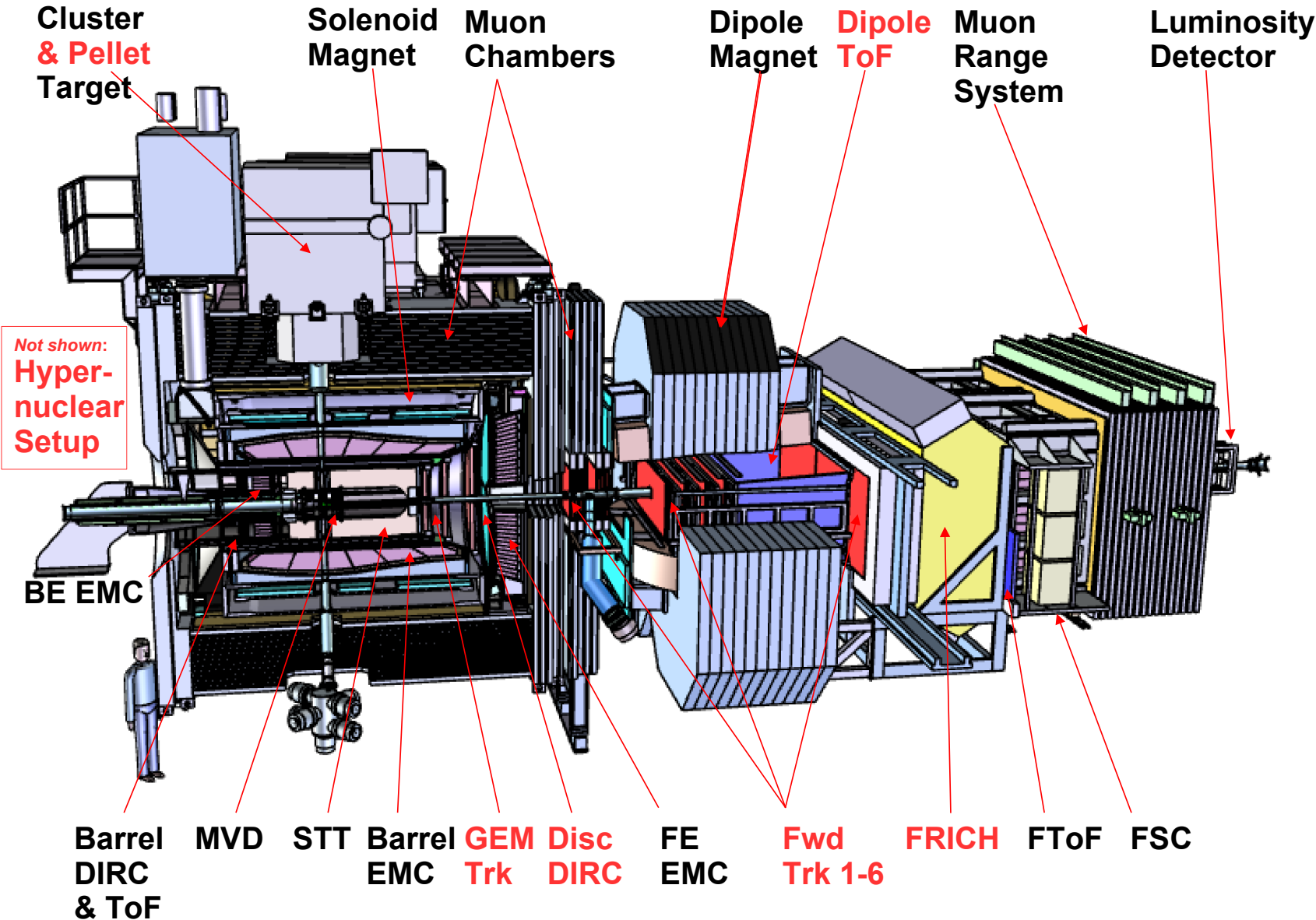
Hypernuclear Physics

- 4π acceptance
- high rate capability (average interaction rate 20 MHz)
- excellent tracking capabilities, momentum resolution 1%
- Vertex reconstruction for D , K_s , hyperons
- good PID (e, μ, π, K, p) \rightarrow Čerenkov, ToF, dE/dx
- γ detection 3 MeV- 10 GeV \rightarrow PWO crystal calorimeter
- continuous data acquisition, no hardware trigger, intelligent software trigger

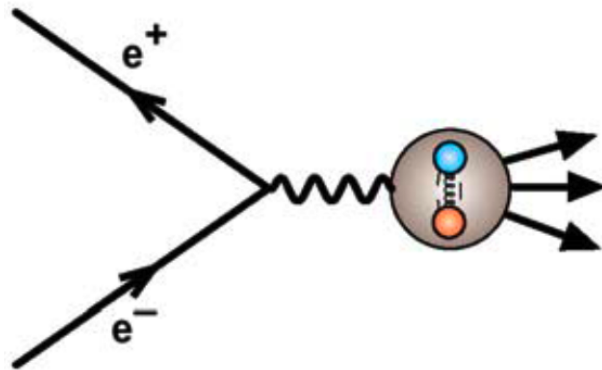
START SETUP



START/ FULL SETUP

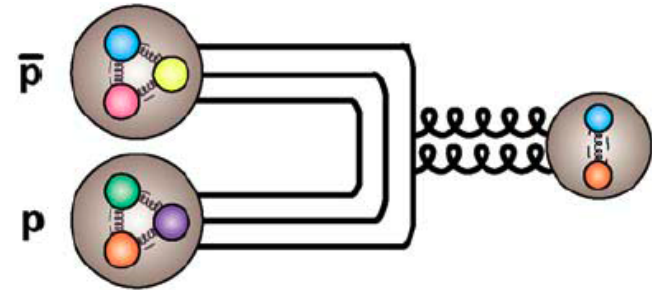


Proton-Antiproton Annihilation

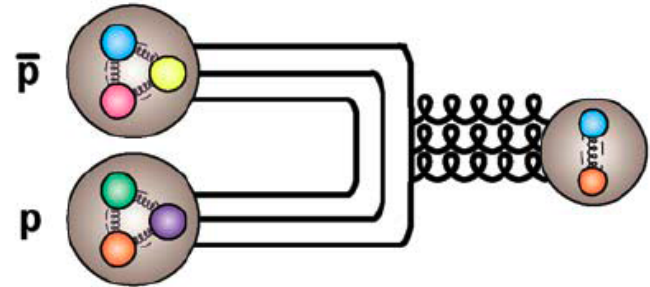


$$J^{PC} = 1^{--}$$

- *Formation:*
→ (precision physics)



$$J = 0, 2, \dots \quad C = +$$



$$J = 1, \dots \quad C = -$$

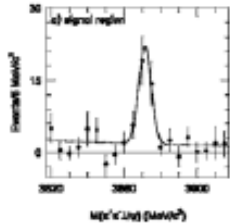
- *q - q bar annihilate into gluons*
- *gluon-rich environment*
- *all quantum numbers allowed by qq bar*



XYZ states

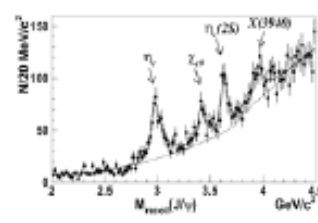
X(3872)

PRL 91,262001 (2003)



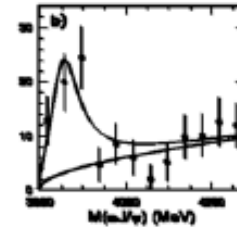
X(3940)

PRL 98,082001 (2007)



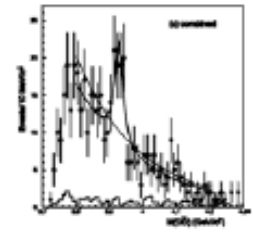
Y(3940)

PRL 94,182002 (2005)



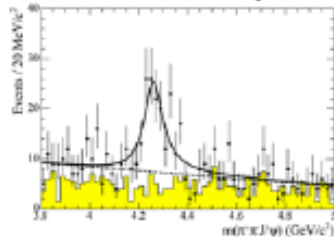
Z(3930)

PRL 96,082003 (2006)



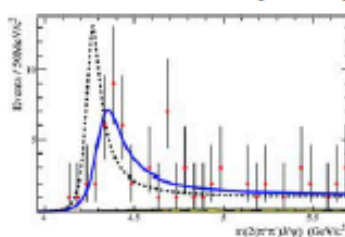
Y(4260)

PRL 95,142001 (2005)



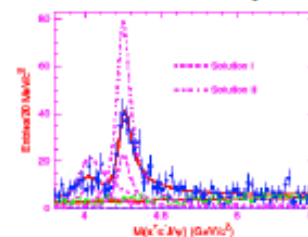
Y(4350)

PRL 98,212001 (2007)



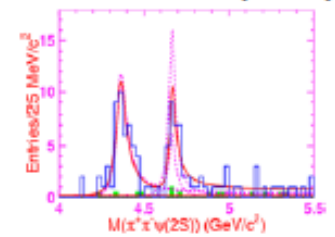
Y(4008)

PRL 99,182004 (2007)



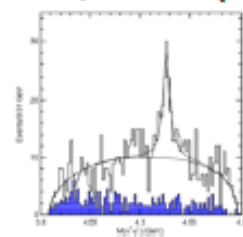
Y(4660)

PRL 99,142002 (2007)



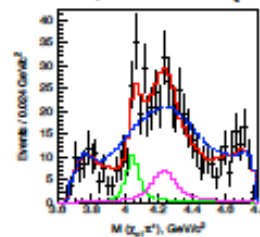
Z(4430)⁺

PRL 100,142001 (2008)



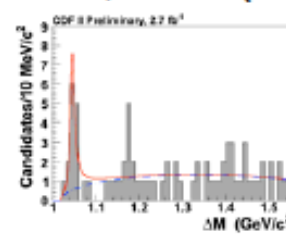
Z₁⁺ & Z₂⁺

PRD 78,072004 (2008)



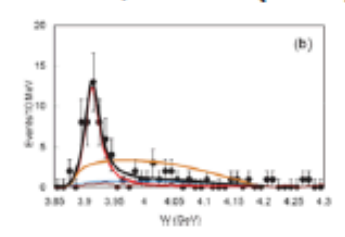
Y(4140)

PRL 102,242002 (2009)



X(3915)

PRL 104,092001 (2010)

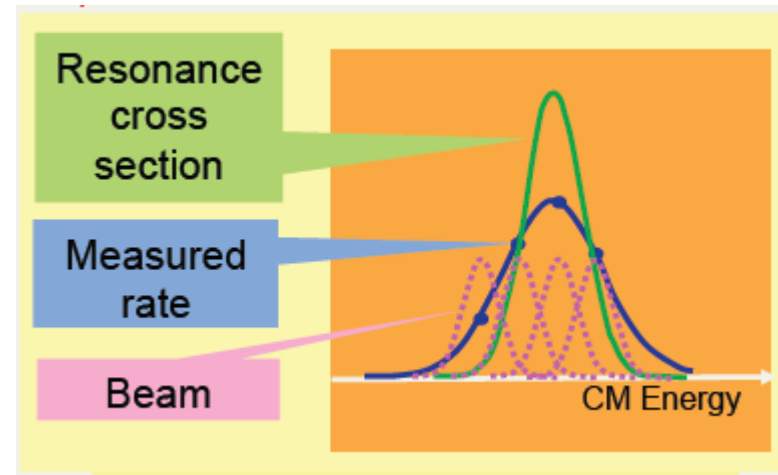
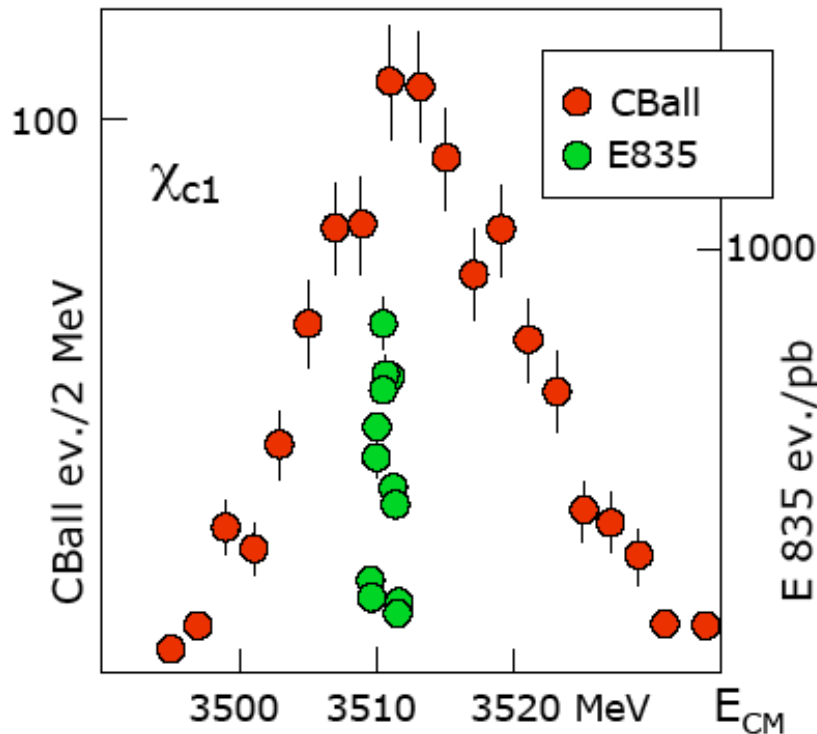


- *What is the nature of these states?*



Search for glueballs, hybrids

Very precise scan of a resonance in formation mode:
depends on HESR beam momentum resolution $\Delta p/p \sim 2 \times 10^{-5}$



Mass resolution

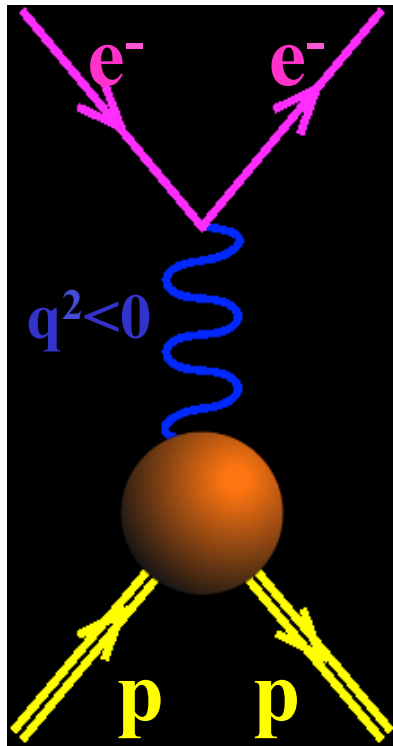
e^+e^-	2 MeV
FermiLab	240 keV
HESR	50 keV

Appearance of a resonance in production mode and disappearance in formation mode sign its exotic nature



Electromagnetic Proton Form Factors

$$\Gamma_\mu = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2M} F_2(q^2)$$



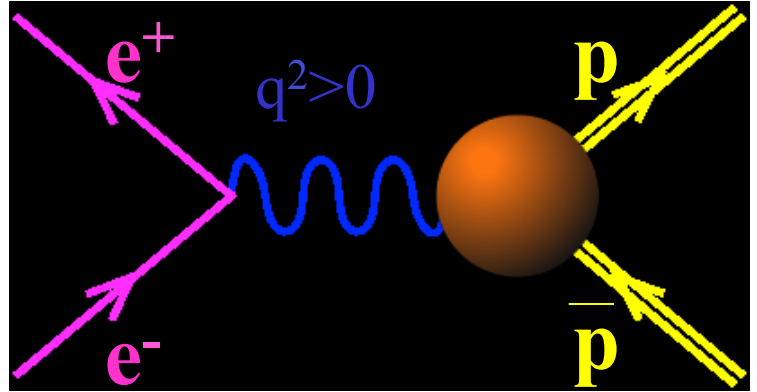
$$GE(0)=1$$

$$GM(0)=\mu_p$$

*Space-like
FFs are real*

*Unphysical region
 $p+\bar{p} \leftrightarrow e^+ + e^- + \pi^0$*

Asymptotics
- QCD
- analyticity



*Time-Like
FFs are complex*

$$e+p \rightarrow e+p$$

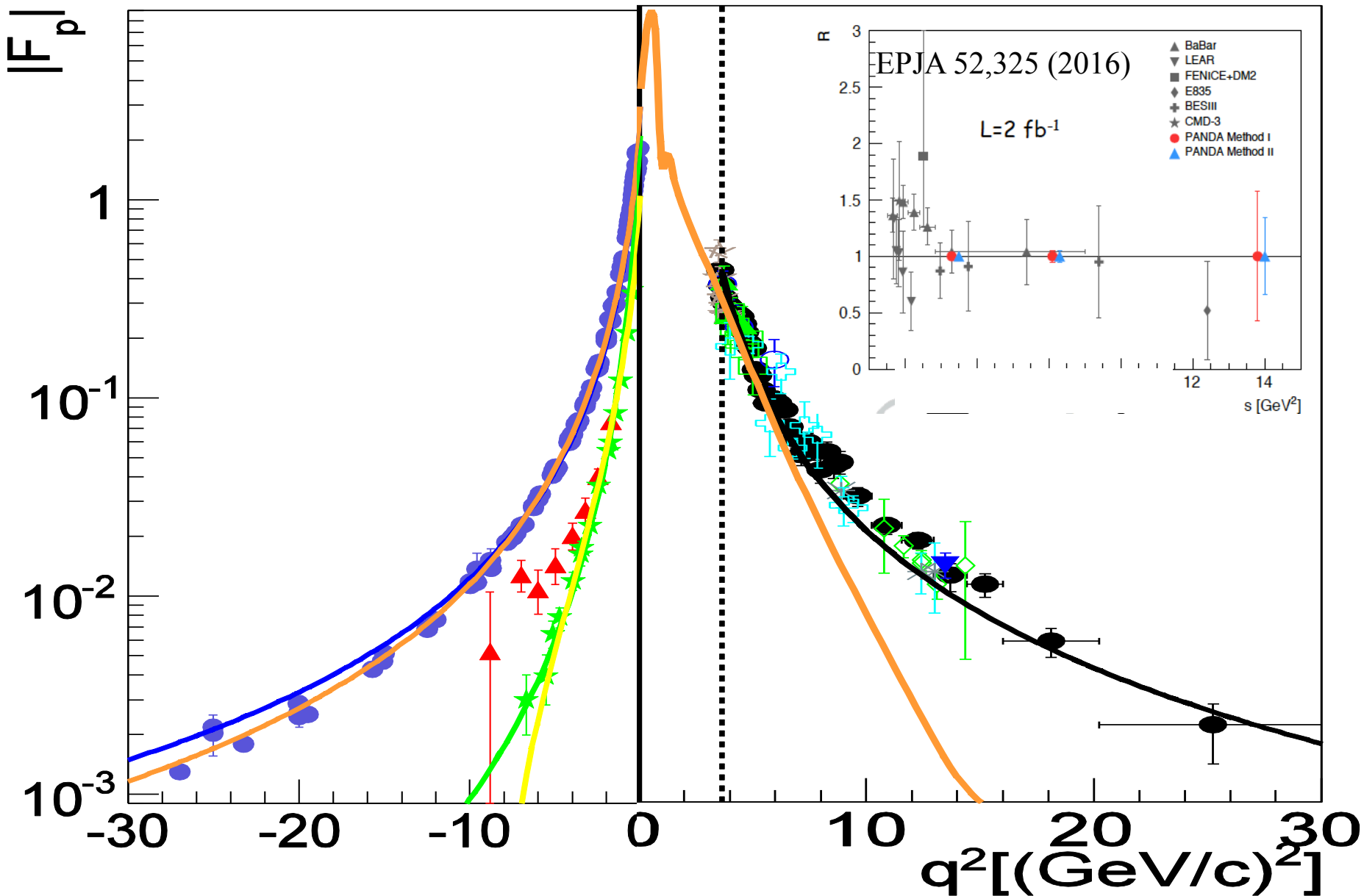
$$0 \quad q^2=4m_p^2$$

$$GE=GM$$

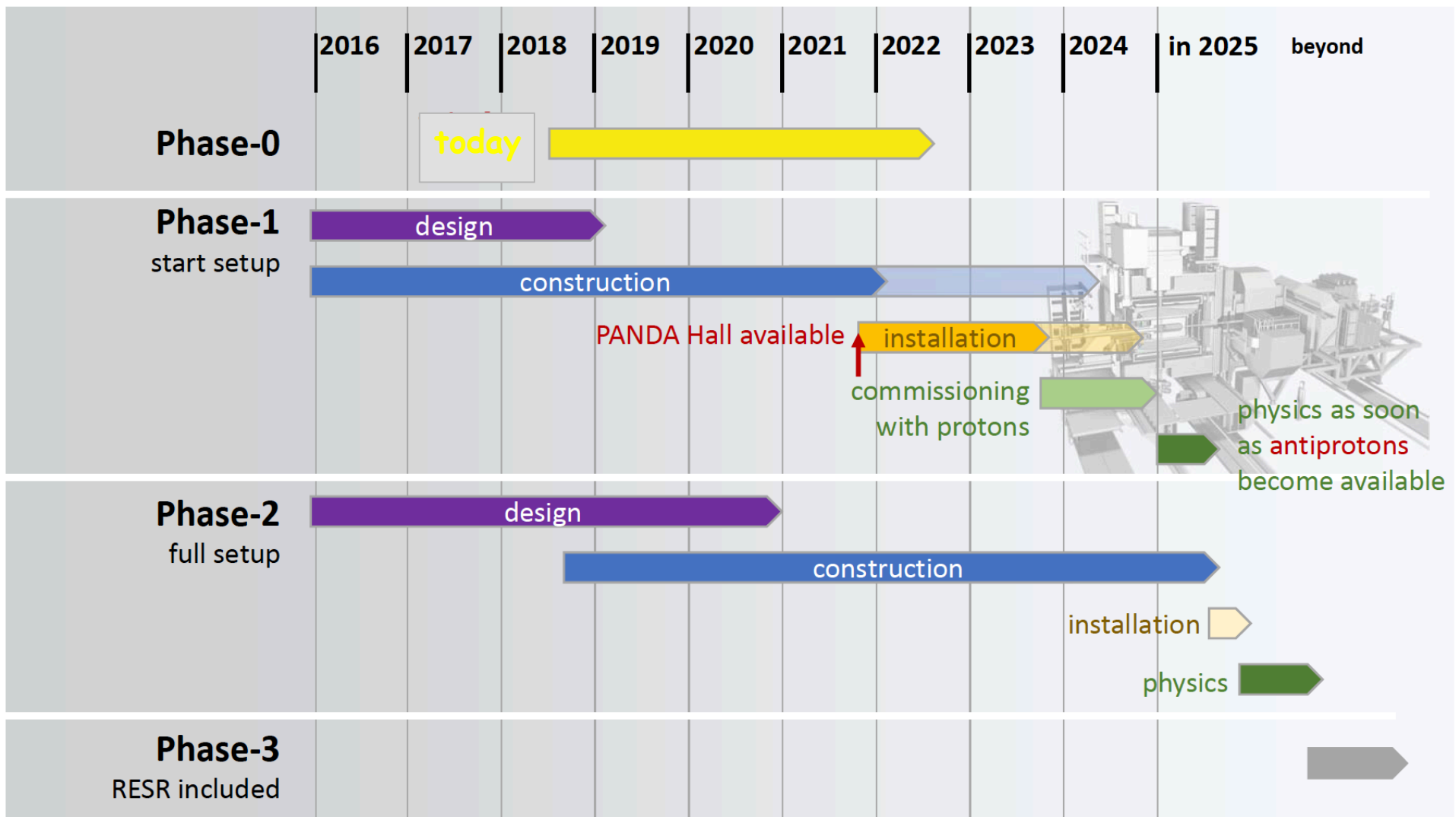
$$p+\bar{p} \leftrightarrow e^+ + e^- \quad q^2$$



Hadron Electromagnetic Form factors

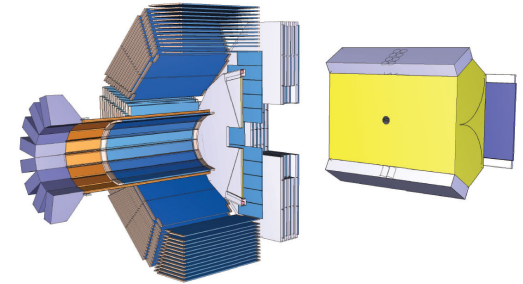
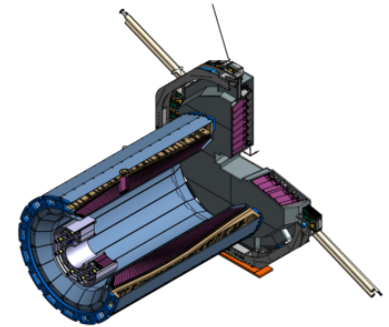


Planning (MSV and beyond)



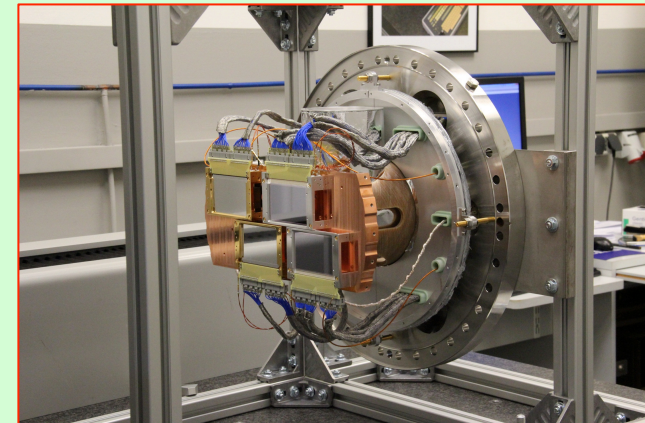
Phase Zero

- **PHASE ZERO: it is NOW!**
 - Prototypes, TDR... mostly ready
 - Detectors are in construction
 - They will be used in running experiments
- **MOU have been signed with**
 - **Hades** (radiative decays of hyperons..)
 - **Jlab** (CLAS, HALL D, analysis, charm...)
 - **MAMI@Mainz** : test of EMC calorimeter, $ep \rightarrow e p l l$, $ep \rightarrow \pi^0 \pi^0$



KOALA@Jülich:

- $p\bar{p}$ elastic scattering
- $0.0005 < |t| < 0.1 \text{ GeV}^2$



The PANDA Collaboration



UniVPM Ancona
U Basel
IHEP Beijing
U Bochum
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
U Cracow
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara

FIAS Frankfurt
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
U Glasgow
BITS Pilani KKBGC,
Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
FH Iserlohn
FZ Jülich
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz

U Mainz
INP Minsk
ITEP Moscow
MPEI Moscow
BARC Mumbai
U Münster
Nankai U
BINP Novosibirsk
Novosibirsk State U
Novosibirsk STU
IPN Orsay
U Wisconsin,
Oshkosh
U & INFN Pavia
Charles U, Prague
Czech TU, Prague
IHEP Protvino
Irfu Saclay
U of Sidney

PNPI St. Petersburg
West Bohemian U,
Pilsen
KTH Stockholm
U Stockholm
Suranaree University
SVNIT Surat-Gujarat
South Gukarat U, Surat-
Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Uppsala
U Valencia
SMI Vienna
U Visva-Bharati
SINS Warsaw

*more than 460 physicists from
from 75 institutions in 19 countries*



Thank you for your attention



2018-03-09 09:00 CET

www.fair-center.eu



PANDA and the World

PANDA	LHCb	Belle2	BES III	JLab	J-PARC	RHIC	Compass	PANDA
Light exotics	Yellow	Yellow	Green with diagonal lines	Green	Yellow	Red	Green with diagonal lines	Green
Charm exotics	Green with diagonal lines	Green with diagonal lines	Green with diagonal lines	Red	Red	Red	Red	Green
Open charm	Green	Green	Green	Red	Yellow	Yellow	Red	Green
Charm in nuclei	Red	Red	Red	Red	Red	Yellow	Red	Green
Multistrange-Baryons	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green
Hyperon spin physics	Red	Red	Red	Yellow	Red	Yellow	Yellow	Green
Time-like form factors	Red	Yellow	Yellow	Red	Red	Red	Red	Green
TMDs	Red	Red	Red	Yellow	Red	Yellow	Yellow	Yellow
GPDs TDAs	Red	Red	Red	Yellow	Red	Yellow	Yellow	Yellow
Hypernuclei	Red	Red	Red	Yellow	Green with diagonal lines	Yellow	Red	Green with diagonal lines

